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ROYAL SIGNALS & RADAR ESTABLISHMENT

MICROWAVE SENSOR DESIGN USING CAD TECHNIQUES

Authors: D Greenhalgh and S J Kidd

PROCUREMENT EXECUTIVE,
MINISTRY OF DEFENCE,
RSRE MALVERN,
WORCS.

UNLIMITED

R"AL SIGNALS AND RADAR ESTABLISHMENT

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AUTHORS: D Greenhalgh and S J Kidd

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SUMMARY

A computer aided design facility is described that enables microwave sensors to be designed and optimised. The facility consists of a suite of computer programme modules, each of which emulates a typical radar subsystem and which may be linked with other modules to emulate a complete system. The sensor environment part of the facility includes both target and clutter models. The sensor hardware part of the facility includes nonlinear effects, and the ability to interchange recorded and simulated signals.

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MICROWAVE SENSOR DESIGN USING CAD TECHNIQUES.

1. INTRODUCTION.

For many years the design and optimisation of a microwave sensor such as a radar has been an expensive evolutionary process requiring many hardware modifications to arrive at a final design. Increased parameter flexibility with multifunction operation has made the design and optimisation procedure much more complicated.

The use of computers in design has been of benefit to many fields notably in the design of modern camera systems and although computer techniques have been applied in microwave systems it has usually been restricted to parametric performance evaluation and specific system performance models.

The purpose of the work outlined in this document is to develop a suite of programmes which will provide a Computer Aided Design (CAD) facility for microwave sensor hardware to:-

1. Simulate advanced radar hardware (phased array radars and signal processing).
2. Simulate '1-on-1' studies for a given radar and particular targets.
3. Assess the value of stealth techniques against radars.

A facility of this type will make a powerful contribution to the work of ME3 division. It will influence the major programmes on phased array antennae and target understanding by rapidly including ideas into a simulation to test their effectiveness against realistic scenarios.

This document is intended to be the first of many reports detailing this work as it progresses and as such it will be confined to an illustration of the problem, the constraints ruling the software design, and an outline specification for each part of the system.

2. ANOTHER SIMULATION?

Why is this simulation different and what is the justification for carrying it out?

Microwave system simulations which have been carried out in the past have not usually been implemented to carry out sensor design, but for other purposes such as the impact of scenario on performance, development of operating procedures, assessment of deployments and operator training. These simulations usually contain a linear transfer function description of the sensor which relates the probability of detection to the target range; but do not take account of the limitations of the hardware or its non-linear interaction with the radar signals.

Where computers have been used in sensor design it has been in the initial design phase to carry out relatively simple but tedious parametric performance calculations. A typical example of this is using the radar equation to check chosen parameters against a radar sensor requirement. Any detailed simulations which have been produced until now have been restricted to the computer assessment of performance for one particular sensor.

What seems to be lacking is a comprehensive suite of programmes which can be used to build and stimulate any sensor at a detailed level (that of non-linear circuits interacting with signals). A detailed simulation such as this allows the sensor hardware to be varied and optimised for the required application. In effect it provides a full computer aided design facility capable of designing many sensors and performing optimisation and trade off calculations on the sensor hardware before the design has been committed.

This memorandum describes the setting up of such a detailed simulation.

3. APPROACH.

The design of a realistic CAD process for microwave sensors requires two areas of work need to be carried out:- the software design and the experimental measurement and validation phase.

3.1. SOFTWARE DESIGN.

The software layout will have a great impact on the package flexibility and its ease of use to the engineer. The many different hardware configurations and environmental conditions required by a flexible package applicable to the majority of microwave sensors implies that the package will be large. In order to have the ability to use real signals and insert real hardware in place of computer modules the interfaces between computer programmes must be constrained to those expected in real systems and are thus sampled signals in the time domain.

In order to design a CAD system to these constraints a modular multilayer approach is required with a 'user friendly' executive used to 'build' the system. A modular approach means that a standard library of programme modules can be used to build different sensors, in much the same way as physical circuit 'modules' are interconnected to make a real sensors.(Figure 1).

A CAD system of this type which is representing sensor hardware interactions with signals has potentially long run times and the adoption of a modular structure has two benefits:-

Firstly a long run time system is sensitive to breaks in computer operations. A modular approach can alleviate this by keeping module sizes to a minimum and inserting storage between modules. A simulation run which has suffered a premature termination can then be easily restarted.

Secondly experiments which are designed to optimise a downstream module would require repeat calculations which may be very time consuming unless the scheme outlined above were adopted. Calculations on different downstream modules are therefore minimised.

A multilayer approach to the simulation means that each programme module has an assocciated data file which can be configured off line.(Figure 2). This eases run time requirements by minimising the calculations required during the run. Programme modules perform operations on the signals by convolutions with the information in the data file or by some transfer function related to that data.

3.2. EXPERIMENTAL VALIDATION.

In this part of the work programme a hierarchy of measurements are required. Firstly experiments on circuit modules will be required to investigate the way in which secondary effects influence the theoretical model. At the next level experiments to determine the effects of interactions between modules will be required and finally system experiments to check the operation of the software sensor and environment representations against real systems.

Assuming that the interfaces have been specified as described above then it is potentially possible to replace software modules with hardware modules, or recorded data from real sources can be introduced into the system, easing the validation process.

4. RECEIVER HARDWARE SIMULATION.

A considerable portion of work has been carried out on this part of the programme to model individual hardware modules such as mixers, amplifiers, Analog to Digital conversion and processing algorithms. An executive programme has also been written for interconnecting the modules. The modules are linked to each other by storage elements and each module rigorously models the subsystem it represents.

The simulation is implemented as a video signal simulation with all modules modelled at baseband. This relies on the fact that mixers perform a linear frequency shift and preserve phase information in this translation. However the operation of non-linear modules during the rf/if stages needs careful attention when translated to baseband and this will be the subject of work over the coming months.

The analog modules operate on voltage waveforms and include all the effects of limited bandwidths, distortions and noise. The simulation of analog modules has to take account of the aliasing problem which occurs in sampled signals and routines have to be developed to minimise these effects.

The simulation of digital modules makes it necessary to model the effects of limited wordlength hardware which required the construction of a completely new set of arithmetic procedures in the computer. The wordlengths of all the digital modules can be varied.

A number of modules have been developed to date, namely:-

- analog amplifiers
- analog mixers
- analog filters including MTI filters
- A/D converters
- digital filters
- window functions
- signal processing modules e.g. FFT, Maximum entropy, Prony algorithm.
- threshold detectors

Along with these modules a comprehensive data input/output facility has been developed using interactive VDU techniques for input and a variety of output channels including printer output, graphical output and magnetic output.

In order show the potential scope of the receiver simulation it will help to look at two examples of what can be done with the simulation in its present form.

4.1 EXAMPLE 1

The first example concerns figures 5 to 14. These show the effect of reducing the wordlength used for the coherent detection of two targets in clutter using an FFT. A digital MTI filter has also been included in the simulation. Three other spectral analysis techniques have also been shown for comparison with the FFT:

- maximum entropy
- Prony algorithm
- sign-log FFT

For simplicity single point unfluctuating targets have been used, although the modular approach used in the simulation does allow for very much more complicated models to be used. The example is described using the following figures to present a visual appreciation of what is happening.

Figure 3 shows a 3-D representation of the simulated video signal. The effects of swept gain have been included. Signal power is shown vertically on a range vs. Doppler grid. The graph illustrates two targets with a ridge of stationary clutter extending in range.

Figure 4 shows a contour map of the final values that are held in the radar digital store after the signal processing. The graph is arranged so that frequency is shown horizontally, and range vertically. The frequency range extends from zero to the sampling

frequency used during the FFT. This explains why the clutter is represented at zero and aliased at the sampling frequency. The effects of clutter and the two targets can be seen. 16 bit arithmetic has been used in the signal processing, and the data has been tapered with a Hamming window.

Figure 5 shows the effect of using a single MTI canceller. The clutter returns have been substantially reduced, but the low frequency target has suffered some attenuation. The returns from the two targets are now clearly visible and detection by a simple threshold detector would be possible. The frequency response for the MTI filter is shown in figure 6.

Figures 7 and 8 show the effect of reducing the wordlength used for the digital signal processing, from 16 to 8 and 5 bits. Reducing the wordlengths makes target detection more difficult.

Figure 9 shows the effect of insufficient dynamic range in the first stages of amplification. The returns from the larger target have been spread in frequency by the limiting action of the overloaded amplifier. Note this graph does not include MTI filtering.

Figures 10, 11 and 12 show the contents of the radar store when maximum entropy, Prony algorithm and sign-log FFT have been used. The ordinates for maximum entropy and Prony have been changed to between zero to half the sampling frequency. Maximum entropy and Prony use the full precision available in the computer and have been included for completeness. The maximum entropy algorithm is based on that published by Barrodale and Erickson (ref 1.), and has located the presence of two targets successfully, but the signal levels are not correct and one could be missed by a subsequent threshold detection. The Prony algorithm has located targets at the correct ranges, but some spurious components have been generated by the noise in the signal. The last figure in this example concerns the sign-log FFT (ref 2). This figure should be compared with figure 8 since the same wordlength is used for both. The improvement with this method is obvious for this wordlength, and an improved performance has also been found with other wordlengths. This has resulted in a more detailed study of this technique.

4.2 EXAMPLE 2

The second example shows the combination of recorded trials data and simulated data in the simulation. The recorded data has been inserted at one of the storage points between programme modules, and the simulated data has been combined using a special module for the purpose.

Recordings of clutter returns from a fully calibrated X-band radar were available. The simulated returns from a moving target was combined with this data. Again for simplicity, a nonfluctuating target was used. Figure 13 shows how this simulation was configured. The functional diagram of the radar was used to design

the modules so that the modelling would be accurate. The target is 0.1m^2 at a range of 1.59 km. The clutter was grass on a windy day.

Figures 14 and 15 show the energy spectrum at the output of the FFT with and without MTI filtering. The MTI filter is again a single stage digital filter.

5. ENVIRONMENT MODELLING.

To complement the receiver hardware simulation, an environment modelling suite of programmes is under development. These will use many of the currently available experimental measurements , well documented in the literature, and the results of new measurements when they becomes available.

Many attempts have been made to characterise clutter returns based on the following parameters (refs 3,4,5):

- ground screening
- operational frequency
- ground slope
- clutter type
- weather conditions
- man made obstacle positions and size
- sea state
- resolution size
- polarisation matrix

A knowledge of the terrain under investigation in terms of the above parameters would enable the simulation to produce realistic returns. A large data base of ground heights enables ground screening and slope to be calculated. As an example, the ground heights and screening for the Malvern area as calculated by the simulation are shown in figures 16 and 17.

The approach taken for this suite of programmes is similar to that already described for the receiver hardware, where programme runs are under the control of a user 'friendly' executive. The detailed description of this environment executive is the subject of a seperate paper.

The environmental programmes interface to the receiver hardware part of the simulation via suitable antenna modules, which under executive control perform a convolution of the complex antenna radiation pattern with the returns from the environment as the antenna rotates.

Several levels of complexity for both target and clutter modelling are envisaged, the use of which would be dependent upon the needs of the current simulation run. For example a comparison of different signal processing algorithms would not necessarily need a detailed aspect dependent target model, but the investigation of a method to detect helicopters in clutter would.

The levels of target model available would include the following:

- point source unfluctuating
- fluctuating point sources with variable statistics
- multiscatterer models based on small scale measurements
- real data

The levels of clutter model available would include the following:

- unfluctuating point sources extending in range
- fluctuating point sources extended in range based on current statistical models
- fluctuating point sources extending in range with statistics dependent upon culture type and conditions
- distributed sources extended in range dependent upon terrain slope and screening
- distributed sources extended in range dependent upon terrain slope and screening with statistics dependent upon culture type
- real data

Simulated and real data can be mixed together as shown in the second example describing the receiver simulation. A wide range of graphical routines are again available to enable the user to understand the output of the simulation. As the simulation grows, it is hoped that all the above aspects would be incorporated, making use measurements and models as they become available.

6. INTERFACE TO OPERATOR.

If the CAD facility is to be used to its full potential, then it is essential that the interface between the operator and the software should be as painless as possible. For this reason, some care has been taken in the software design to allow modules to be specified, changed, inserted and deleted easily. This has been achieved by adopting a hierarchical programme structure.

An executive program allows the user to respond to a limited but 'friendly' set of instructions. This response in then tested for validity and the operating system commands required to implement the desired operation are put out to a file which is then immediately obeyed. Once the operation is complete, the executive programme automatically reloads and runs, asking for the next action to be taken. This approach is extended into all the program modules, allowing for easy expansion. For example, if a filter was to be changed, an introductory filter programme would be initiated which asks for a selection to be made from the variety of filter design programmes. Once the selection is made, the appropriate design program is obeyed, the user only having to respond to the prompts.

To aid the design process, many design programmes produce graphs and useful information on the terminal display as the design proceeds. The user is then prompted to decide if the design is satisfactory.

If it is, the the data file connected with the module is loaded. Figure 6 is an example from a digital filter design programme.

The network facilities connected to the mainframe computer allow any remote terminal or computer to operate the simulation. Data could also be passed between the remote terminal and the host, or real hardware and host in several permutations. At present the simulation has been run successfully from a BBC microcomputer and a Hewlett Packard 9845, including the graphical output.

7. SIMULATION USES.

The simulation suite described can not only be used to predict the performance of a given radar on a particular site, but is intended to be used for some particular applications, where the usual parametric approach cannot be used:

- Calibration of radar systems by producing returns from simulated targets, the behaviour of which is well known.
- Designing special methods to detect difficult targets at microwave frequencies, for example helicopters.
- Assessing the performance of target classification techniques at millimeter waves, when the limitations of real hardware are imposed upon the designs.
- Further work to assess different algorithms for enhancing radar signal processing.
- Examining cost/performance tradeoffs for SHORAD and battlefield radar.
- Simulated performance trials of microwave radars against certain classes of target using different scenarios or target behaviour.
- Determining the effects of nonlinear components within the radar system on overall performance. Examples of this would be determining:
  a) how much distortion in a first stage amplifier would be acceptable before performance was significantly degraded,
  b) establishing what wordlength should be used in the digital signal processing,
  c) the difference between using analog and digital techniques to discriminate doppler returns.
- Simulate advanced radar hardware.
- Assessment of stealth techniques against radars.

8. FURTHER WORK

As stated in the introduction, this report is intended to be the first of many explaining the work of the CAD facility as it progresses. Further work topics include:

Sensor :-Improvement of the antenna interface between the environment and receiver hardware, to include azimuth and elevation response.
-Improving the accuracy of the hardware emulation, based on experimental results and investigation of the effects of baseband modelling.

Environment:-
-Validation of the clutter models used, with available experimental measurements.
-Include target screening by the terrain.
-Include ECM modules.
-Include target multipath reflections.
-Including the multisource aspect dependent target models from scaled RF measurements.

9. CONCLUSION.

The aim of this report has been to present an outline of the CAD facility under developement, giving a description of the software design and the system capabilities. It was emphasised that the need for a simulation of this type has arisen because of the limitations of the usual parametric approaches. The most notable of these being the inclusion of the nonlinear effects caused by real hardware and the ability to interchange real and simulated data. The detailed description of specific areas within the CAD facility will be the topics of other papers published as the work progresses.

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3. F.E. Nathanson
   Radar Design Principles
   Chapter 7.

4. D.K. Barton
   Radar System Analysis
   Chapter 3.

5. M. Skolnik
   Radar Handbook

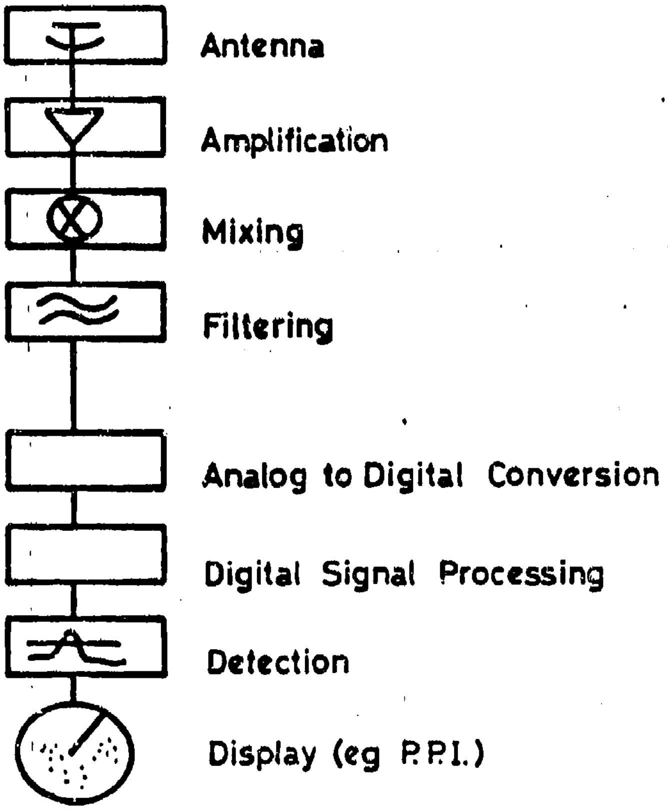


FIG.1. A RADAR SYSTEM BUILT OUT OF MODULES

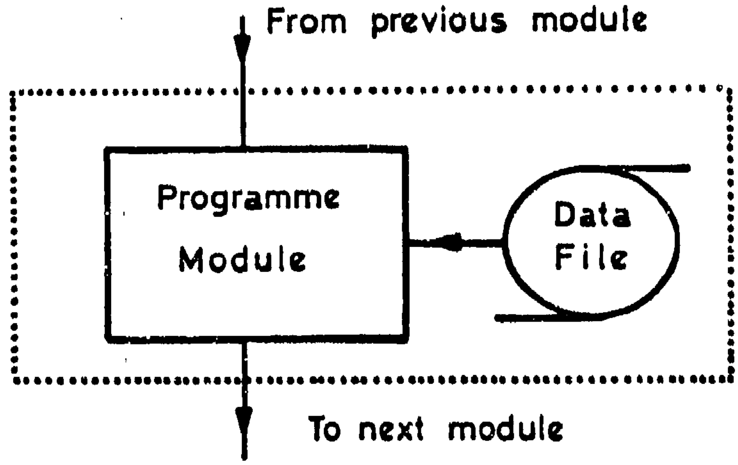


FIG. 2. A TYPICAL MODULE WITH ITS DATA FILE

PRODUCED BY ':WI.SJK-VTBI' ON 19JAN84 AT 11.41.07 2

SIGNAL POWER AT ANTENNA VS RANGE AND DOPPLER FREQUENCY

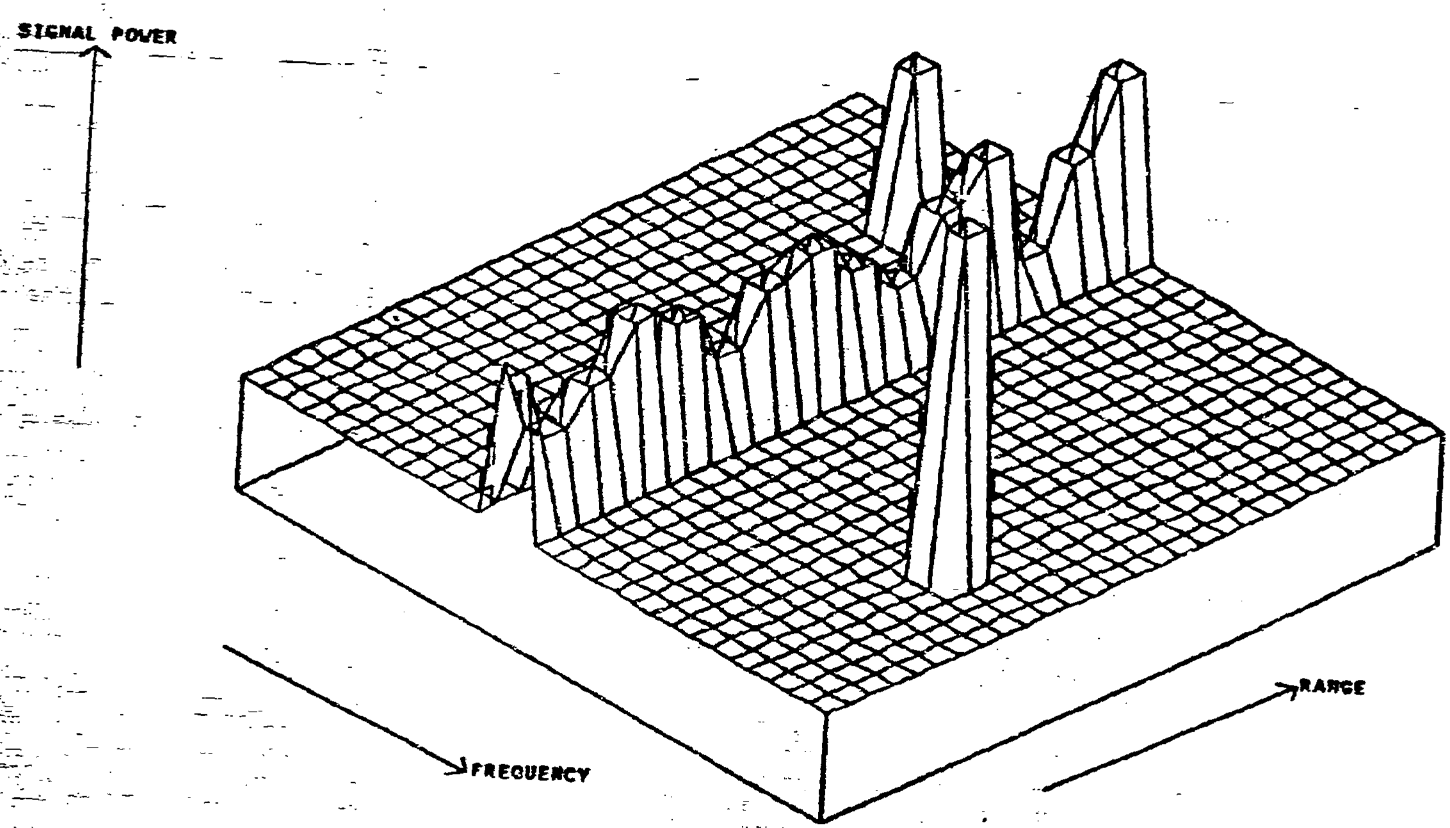
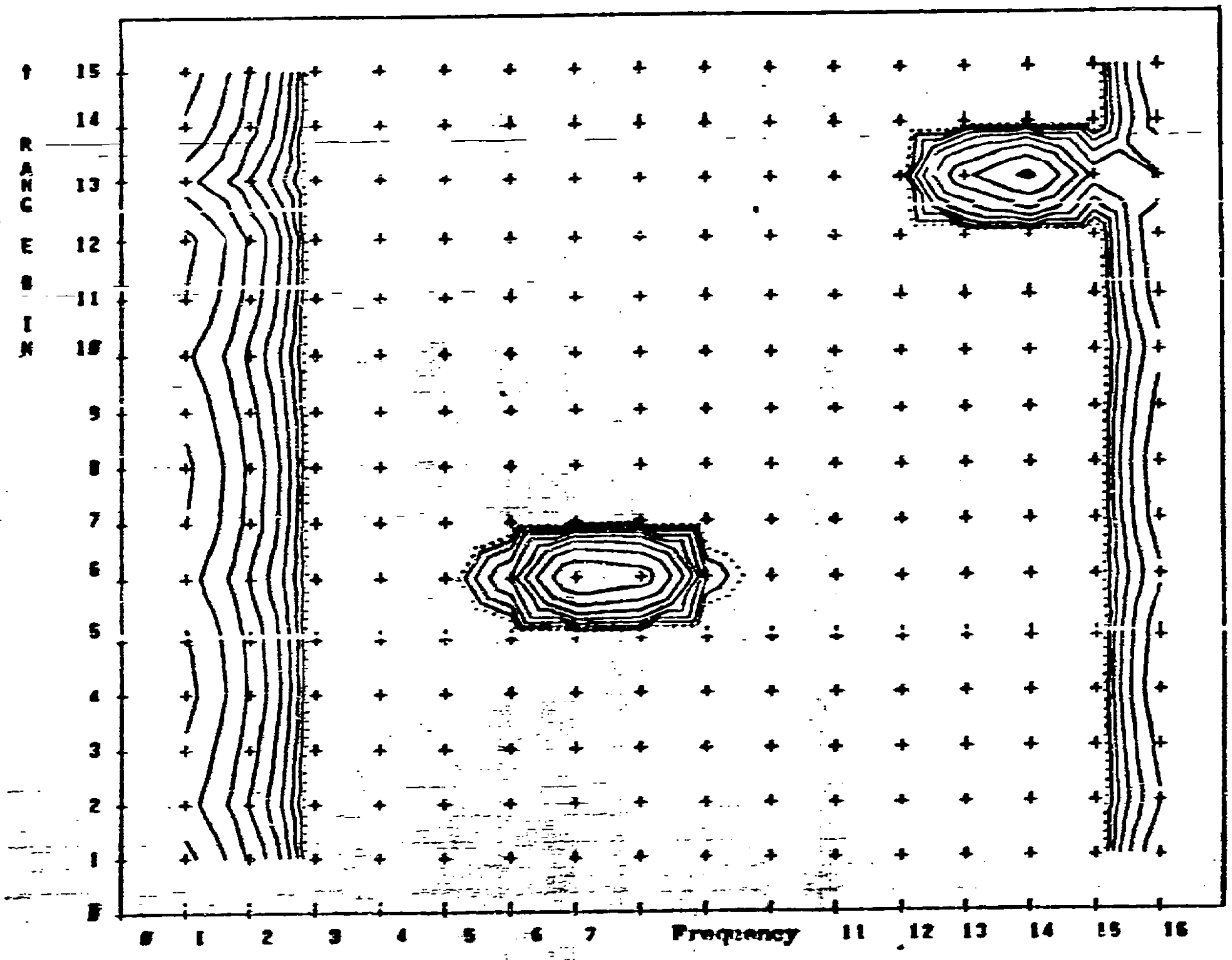


FIGURE 3

PRODUCED BY '.W1.GJK-VT32' ON 19JAN84 AT 14.26.37 1

RADAR HARDWARE SIMULATION = SIGNAL PROCESSING OUTPUT

CONTOUR HEIGHTS ARE 3DB INTERVALS



WINDOW DATA

WINDOW		CALCULATION	
MANT	EXP	MANT	EXP
16	0	16	0

SIDELOBES(DB)	TYPE
40.0	2

1-UNIFORM
2-HAMMING
3-DOLPHCHEBY
4-KAISER
5-TAYLOR

FFTDATA

CALCULATION

MANT(INT)	EXP(INT)
16	0

FFT WEIGHTS

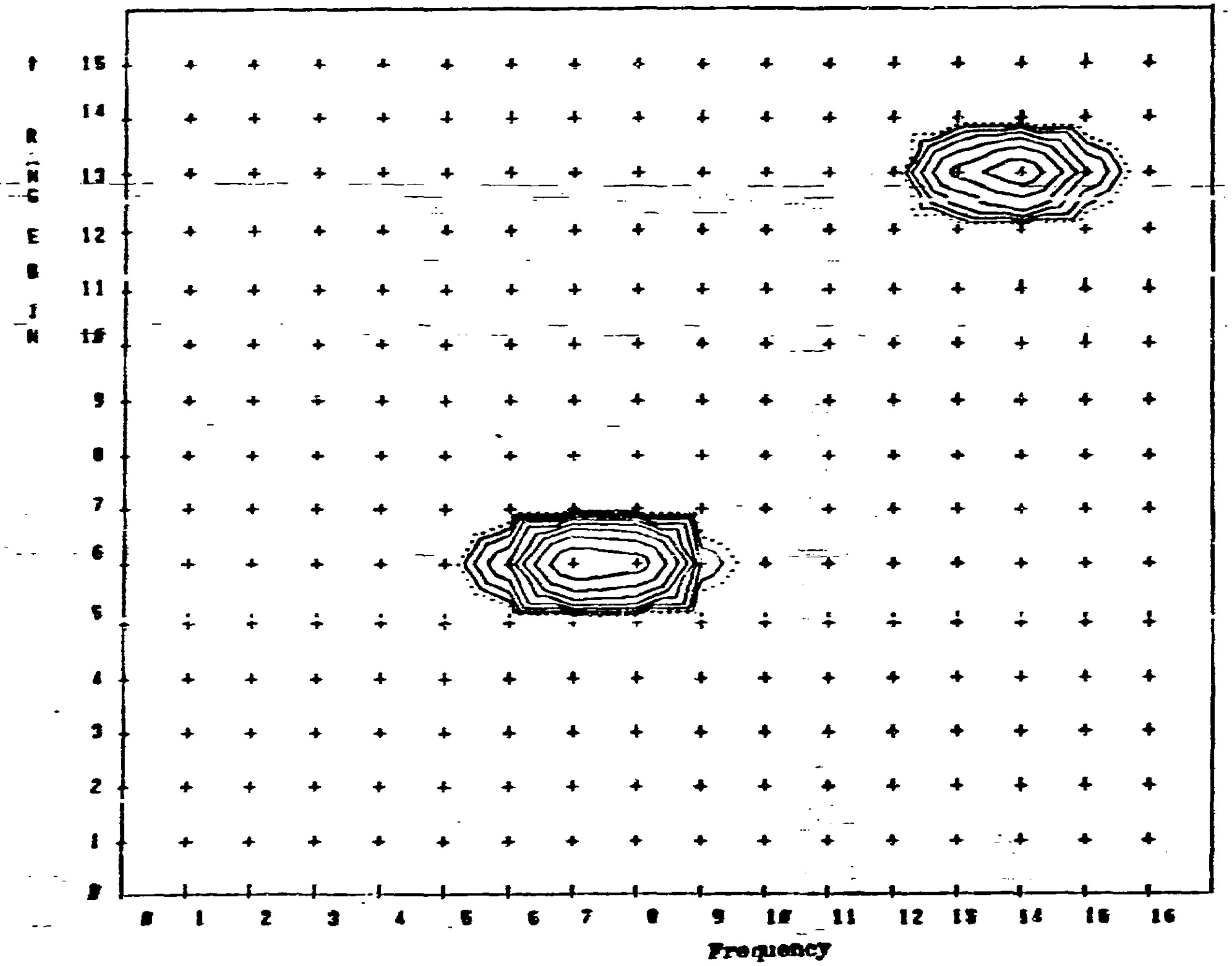
MANT(INT)	EXP(INT)
16	0

FIGURE 4

PRODUCED BY ':W1.SJK-VT32' ON 19JAN84 AT 14.34.23 1

RADAR HARDWARE SIMULATION - SIGNAL PROCESSING OUTPUT

CONTOUR HEIGHTS ARE 3DB INTERVALS



WINDOW DATA

WINDOW		CALCULATION	
MANT	EXP	MANT	EXP
16	0	16	0

SIDELOBES(DB)	TYPE
40.0	2

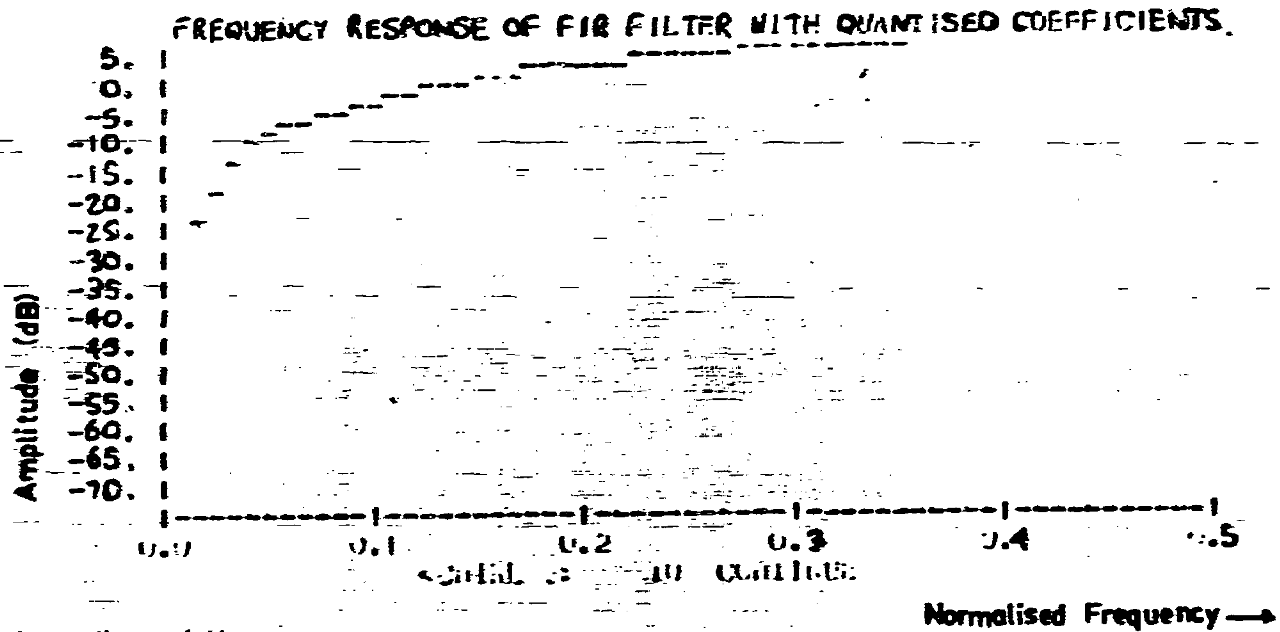
1-UNIFORM
2-HAMMING
3-DOLPHCHEBY
4-KAISER
5-TAYLOR

FFTDATA

CALCULATION	
MANT(INT)	EXP(INT)
16	0

FFT WEIGHTS	
MANT(INT)	EXP(INT)
16	0

FIGURE 5



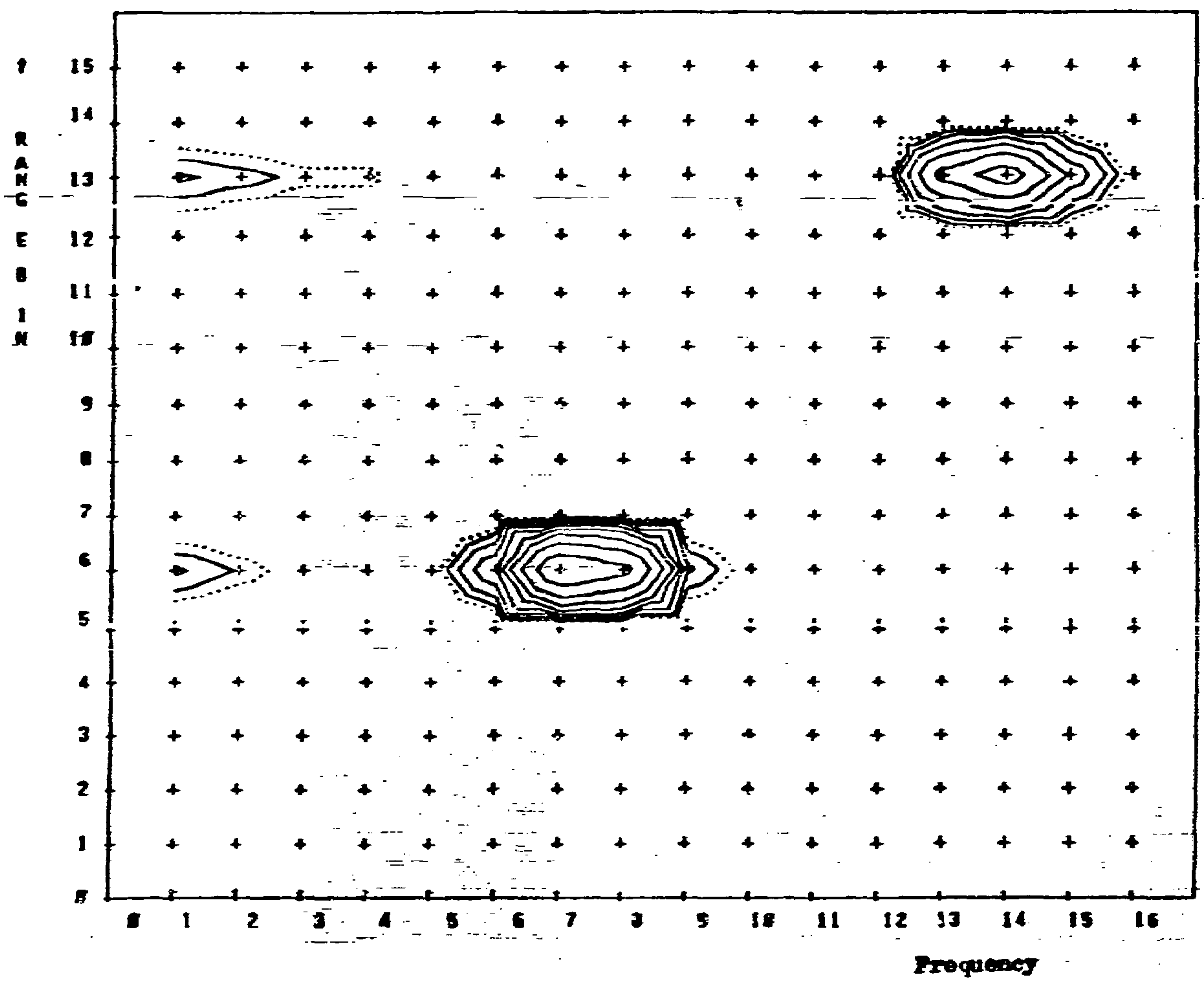
FREQUENCY RESPONSE OF FIR FILTER WITH QUANTISED COEFFICIENTS.
Amplitude (dB)
5.
0.
-5.
-10.
-15.
-20.
-25.
-30.
-35.
-40.
-45.
-50.
-55.
-60.
-65.
-70.
0.0
0.1
0.2
0.3
0.4
0.5
Normalised Frequency

FIGURE 6

PRODUCED BY '(WI,SJK-VT32' ON 19JAN84 AT 14.50.14   1

RADAR HARDWARE SIMULATION - SIGNAL PROCESSING OUTPUT

CONTOUR HEIGHTS ARE 3DB INTERVALS



WINDOW DATA

WINDOW		CALCULATION	
MANT	EXP	MANT	EXP
0	0	0	0

SIDELOBES(DB)	TYPE
40.0	2

1-UNIFORM
2-HAMMING
3-DOLPHCHEBY
4-KAISER
5-TAYLOR

FFTDATA

CALCULATION

MANT(INT)	EXP(INT)
0	0

FFT WEIGHTS

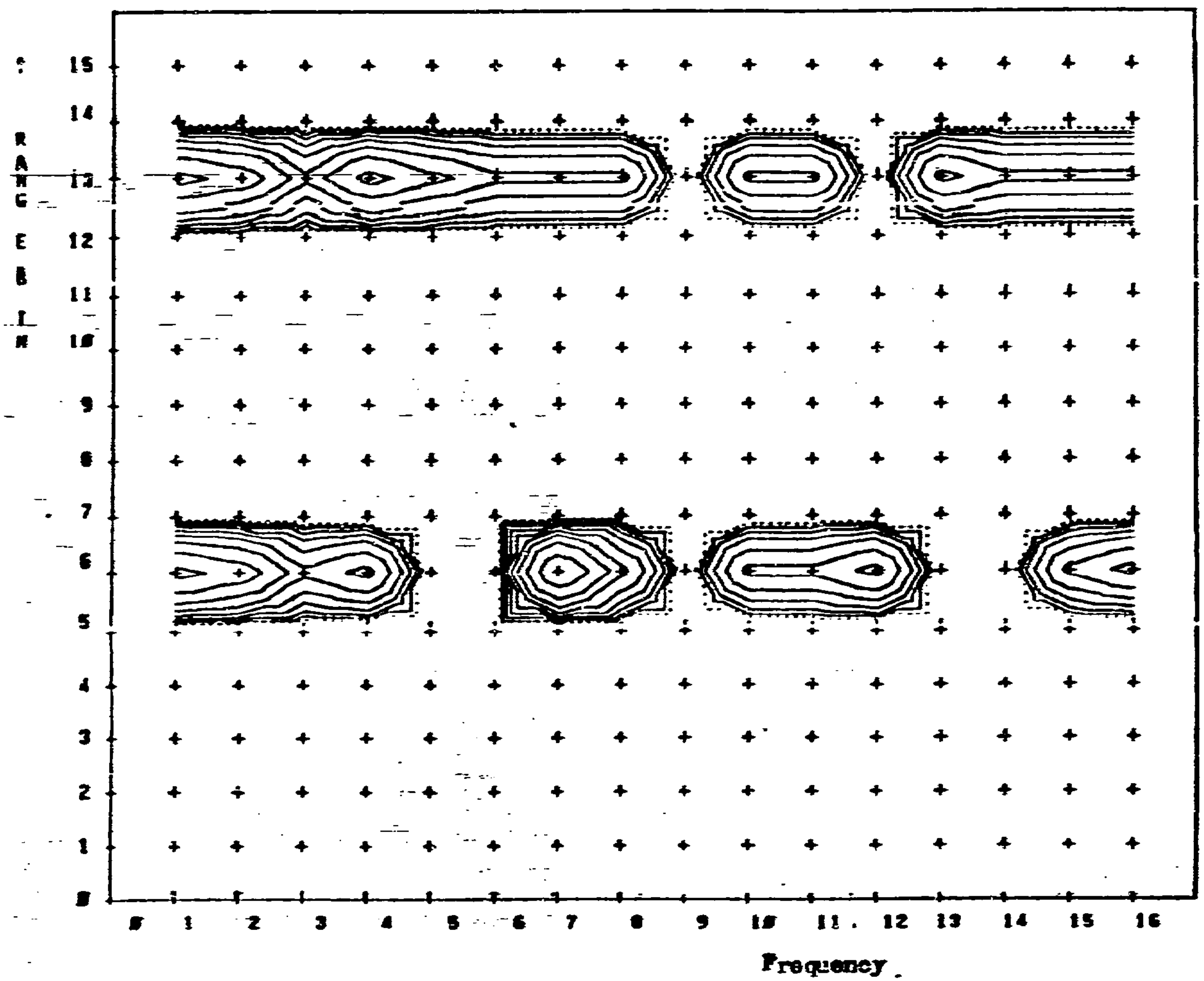
MANT(INT)	EXP(INT)
0	0

FIGURE 7

PRODUCED BY ':VI.SJK-VT32' ON 19JAN84 AT 14.55.50   1

RADAR HARDWARE SIMULATION - SIGNAL PROCESSING OUTPUT

CONTOUR HEIGHTS ARE 3DB INTERVALS



WINDOW DATA

WINDOW MANT	WINDOW EXP	CALCULATION MANT	CALCULATION EXP
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SIDELOBES(DB)	TYPE
40.0	2

1-UNIFORM
2-HAMMING
3-DOLPHCHEBY
4-KAISER
5-TAYLOR

FFTDATA

CALCULATION

MANT(INT)	EXP(INT)
6	0

FFT WEIGHTS

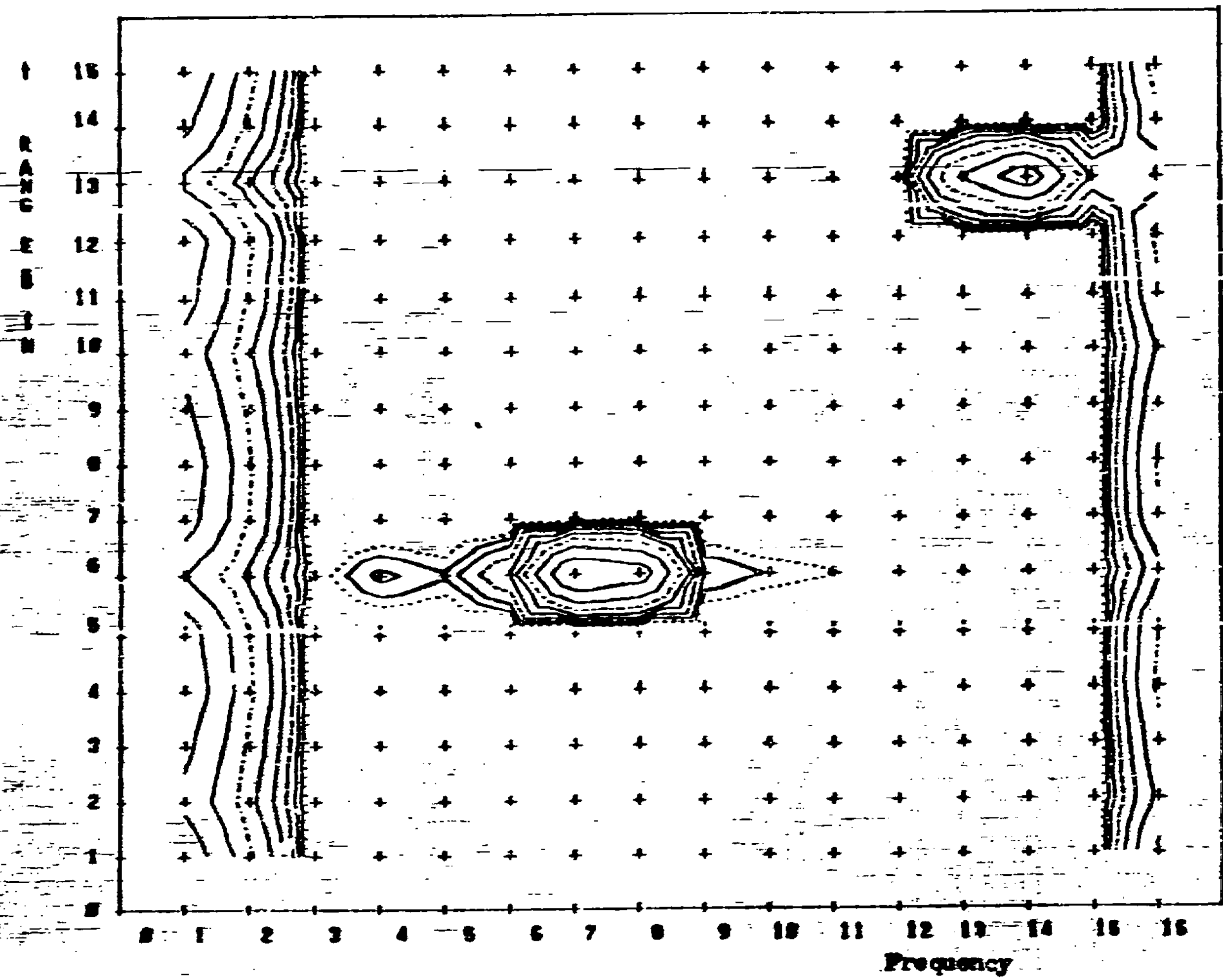
MANT(INT)	EXP(INT)
5	0

FIGURE 8

PRODUCED BY ':V1.SJK-VT01' ON 17JAN84 AT 14.16.35 1

RADAR HARDWARE SIMULATION - SIGNAL PROCESSING OUTPUT

CONTOUR HEIGHTS ARE 3DB INTERVALS



WINDOW DATA

WINDOW MANT	WINDOW EXP	CALCULATION MANT	CALCULATION EXP
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SIDELOBES(DB)	TYPE
40.0	2

1-UNIFORM
2-HAMMING
3-DOLPHCHEBY
4-KAISER
5-TAYLOR

FFTDATA

CALCULATION

MANT(INT)	EXP(INT)
15	0

FFT WEIGHTS

MANT(INT)	EXP(INT)
16	0

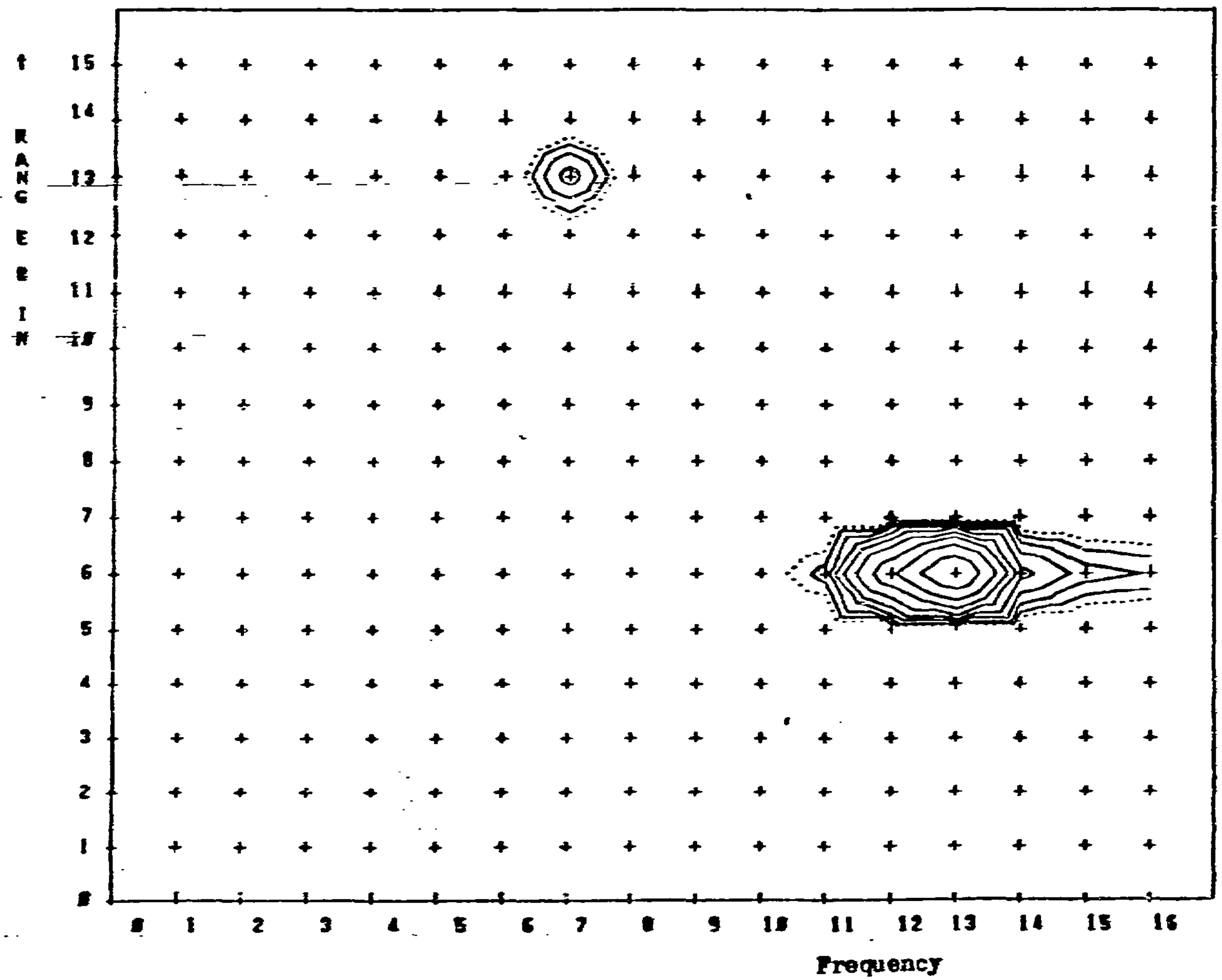
Overloaded amplifier

FIGURE 9

PRODUCED BY ':W1.SJK-VT32' ON 19JAN84 AT 16.01.23 1

RADAR HARDWARE SIMULATION - SIGNAL PROCESSING OUTPUT

CONTOUR HEIGHTS ARE 3DB INTERVALS



WINDOW DATA

WINDOW		CALCULATION	
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SIDELOBES(DB)	TYPE
0.0	1

1-UNIFORM
2-HAMMING
3-DOLPHCHEBY
4-KAISER
5-TAYLOR

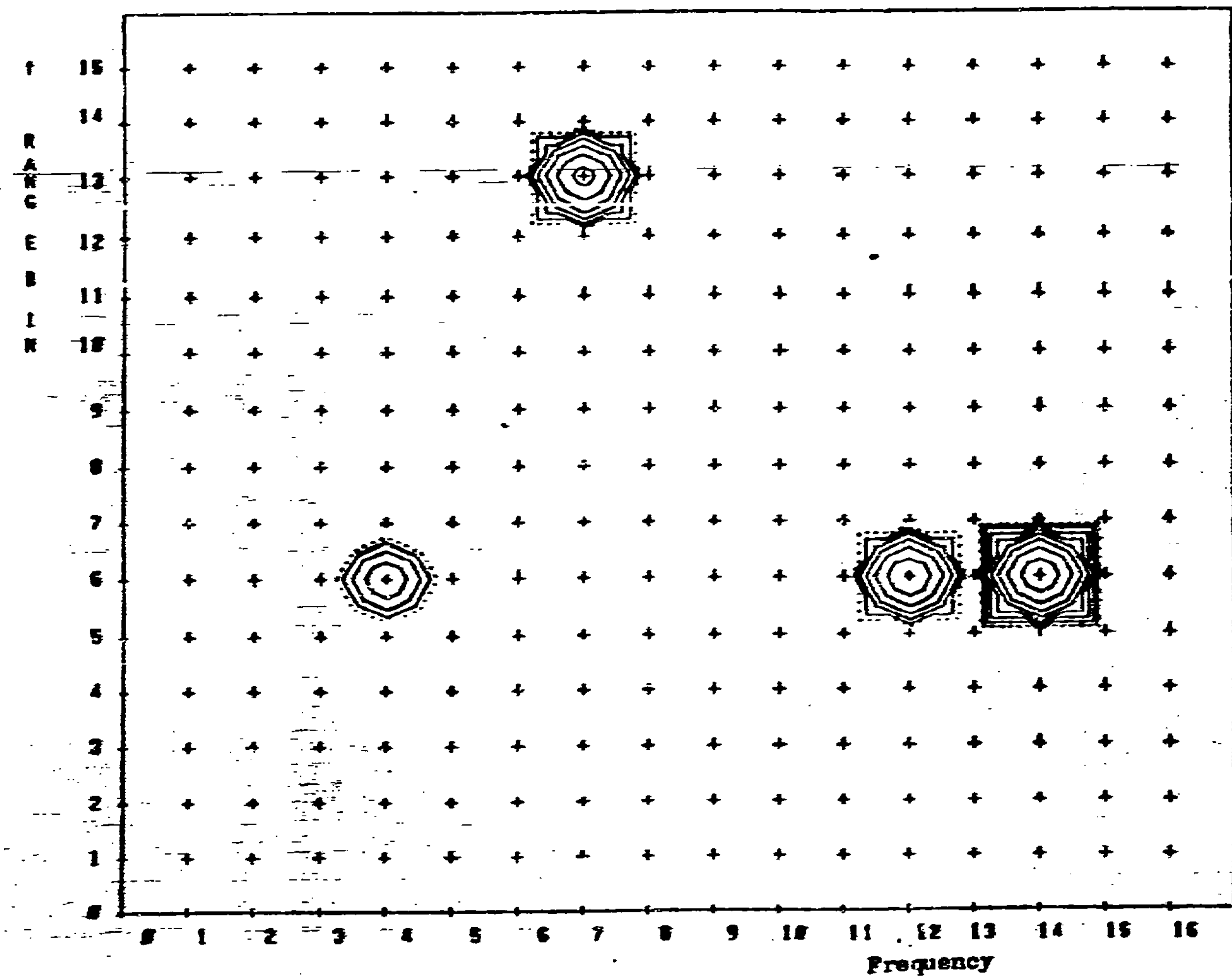
MAXIMUM ENTROPY

FIGURE 10.

PRODUCED BY ':W1.SJK-VT32' ON 19JAN84 AT 15.16.56 1

RADAR HARDWARE SIMULATION - SIGNAL PROCESSING OUTPUT

CONTOUR HEIGHTS ARE 3DB INTERVALS



WINDOW DATA

WINDOW		CALCULATION	
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SIDELOBES(DB) 0.0 TYPE 1

1-UNIFORM
2-HAMMING
3-DOLPHCHEBY
4-KAISER
5-TAYLOR

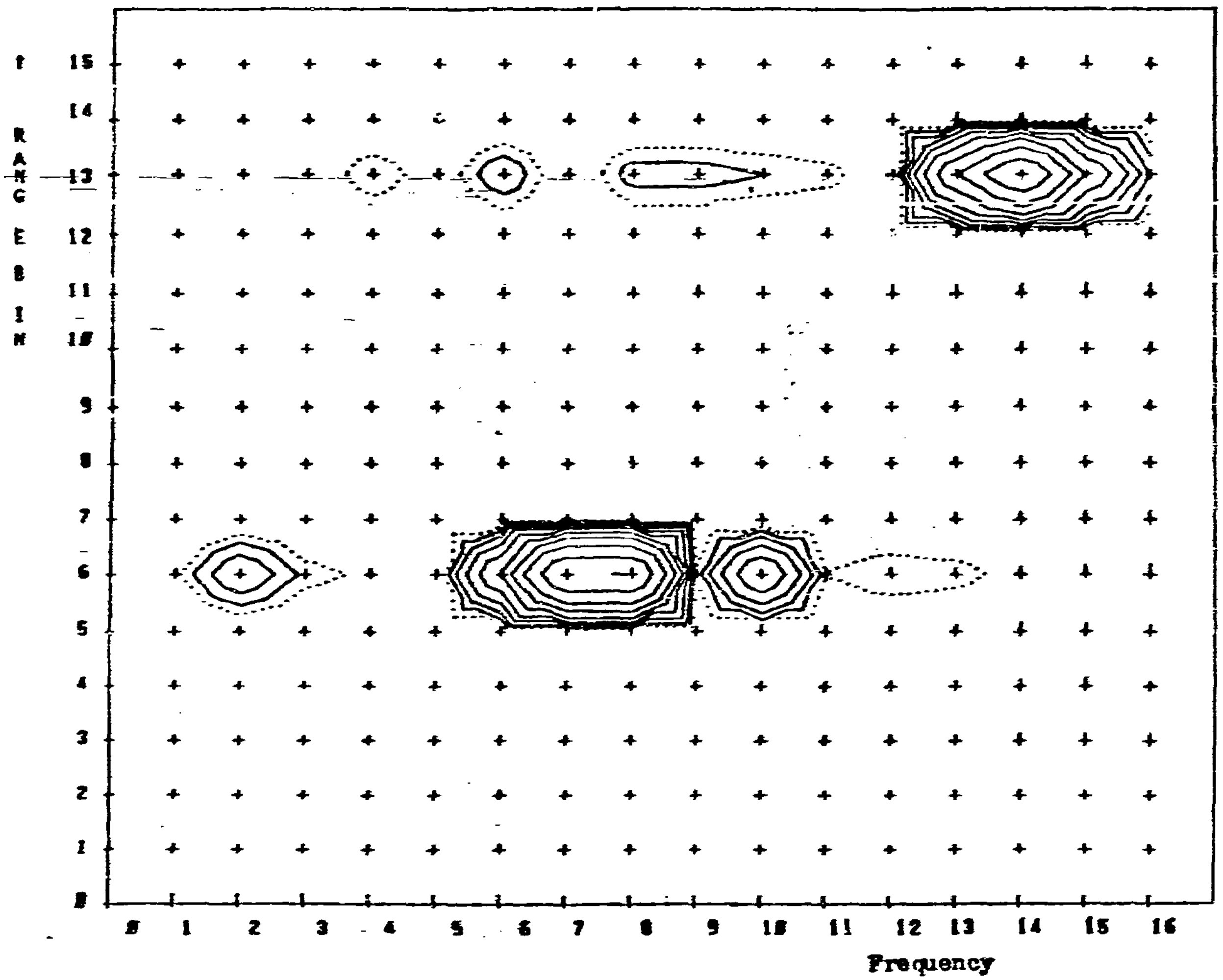
PRONY ALGORITHM

FIGURE II

PRODUCED BY 'IWI.SJK-VT32' ON 19JAN84 AT 16.43.36 1

RADAR HARDWARE SIMULATION - SIGNAL PROCESSING OUTPUT

CONTOUR HEIGHTS ARE 3DB INTERVALS



LOGARITHM PROCESS DATA

WINDOW		CALCULATION	
BITS	FRAC	MANT	EXP
5	1	6	0

SIDELOBES(DB)	TYPE
40.0	2

1-UNIFORM
2-HAMMING
3-DOLPHCHEBY
4-KAISER
5-TAYLOR

Sign-log F.F.T.

FIGURE 12

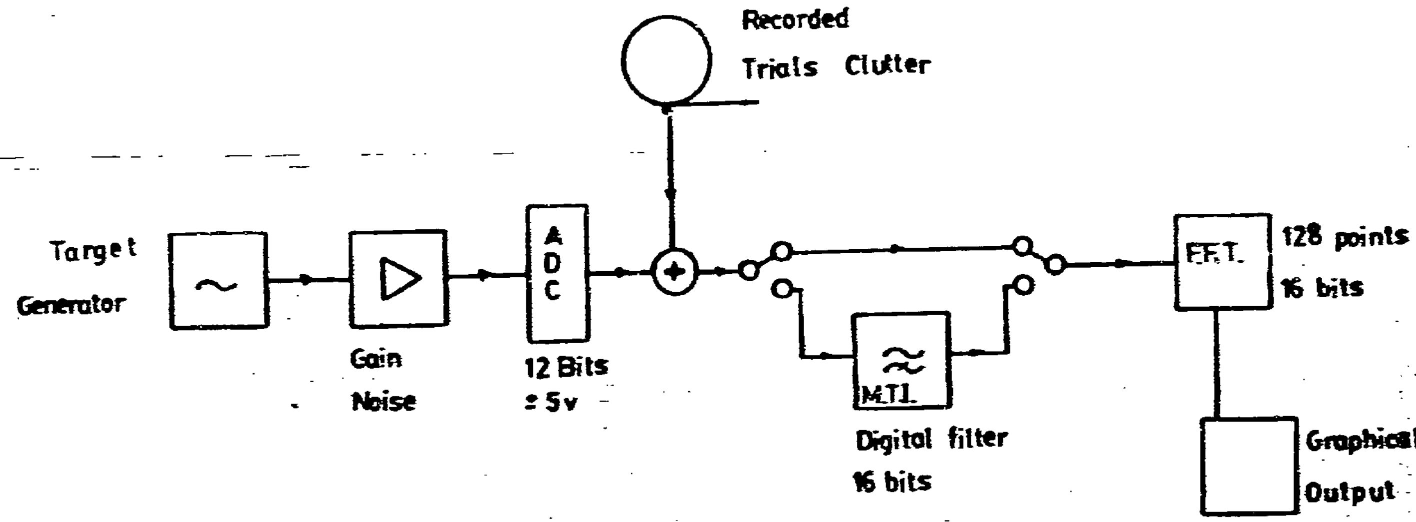


FIGURE 13. Combining Simulated and Real Data.

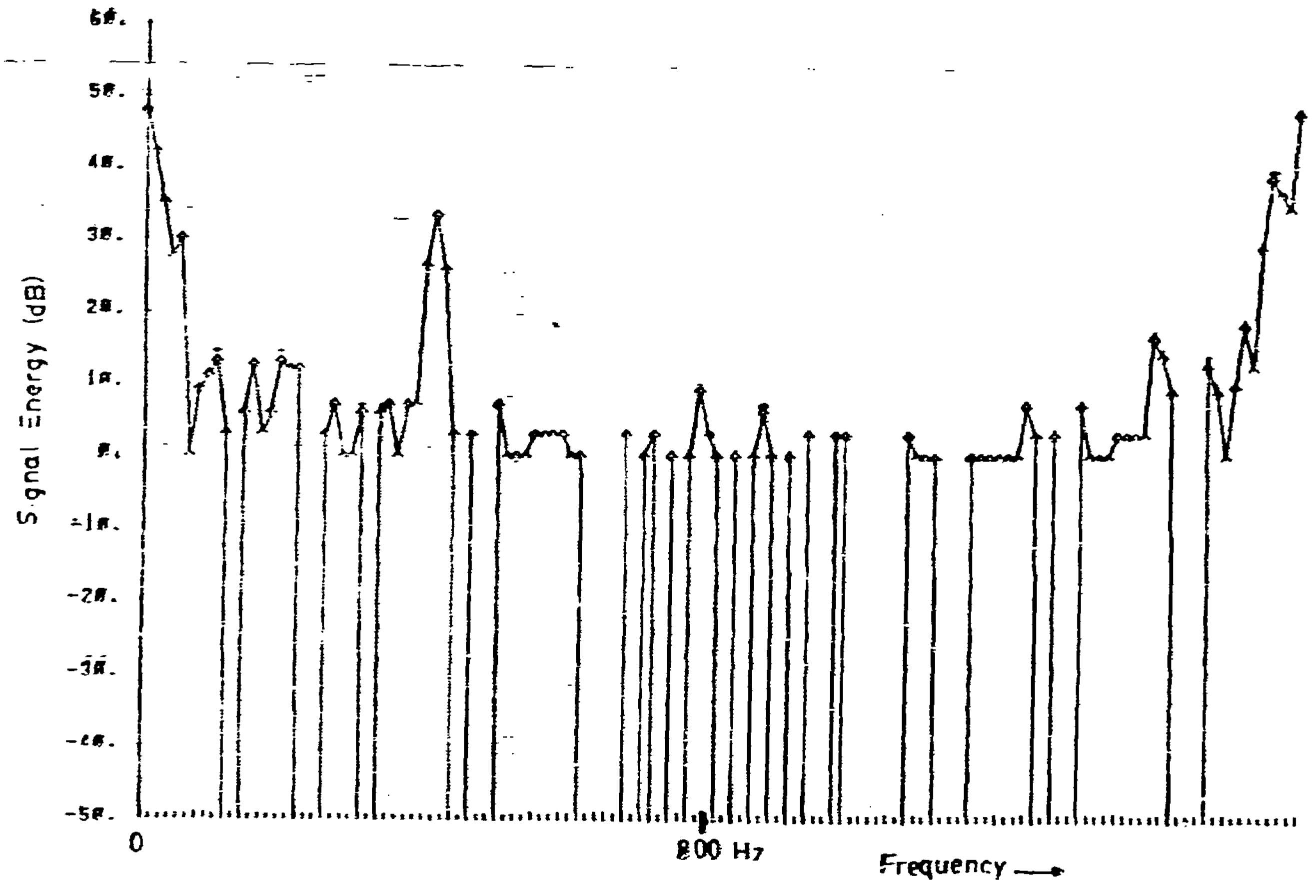
PRODUCED BY [illegible] ON 15MAR82 AT 14.14.38

RADAR HARDWARE SIMULATION -- SIGNAL PROCESSING OUTPUT

NO. OF BINS 8

NO. OF PULSES 128

P.R.I. 625.000 US



0.1 m^2 target at 1.59 Km

FIGURE 14.

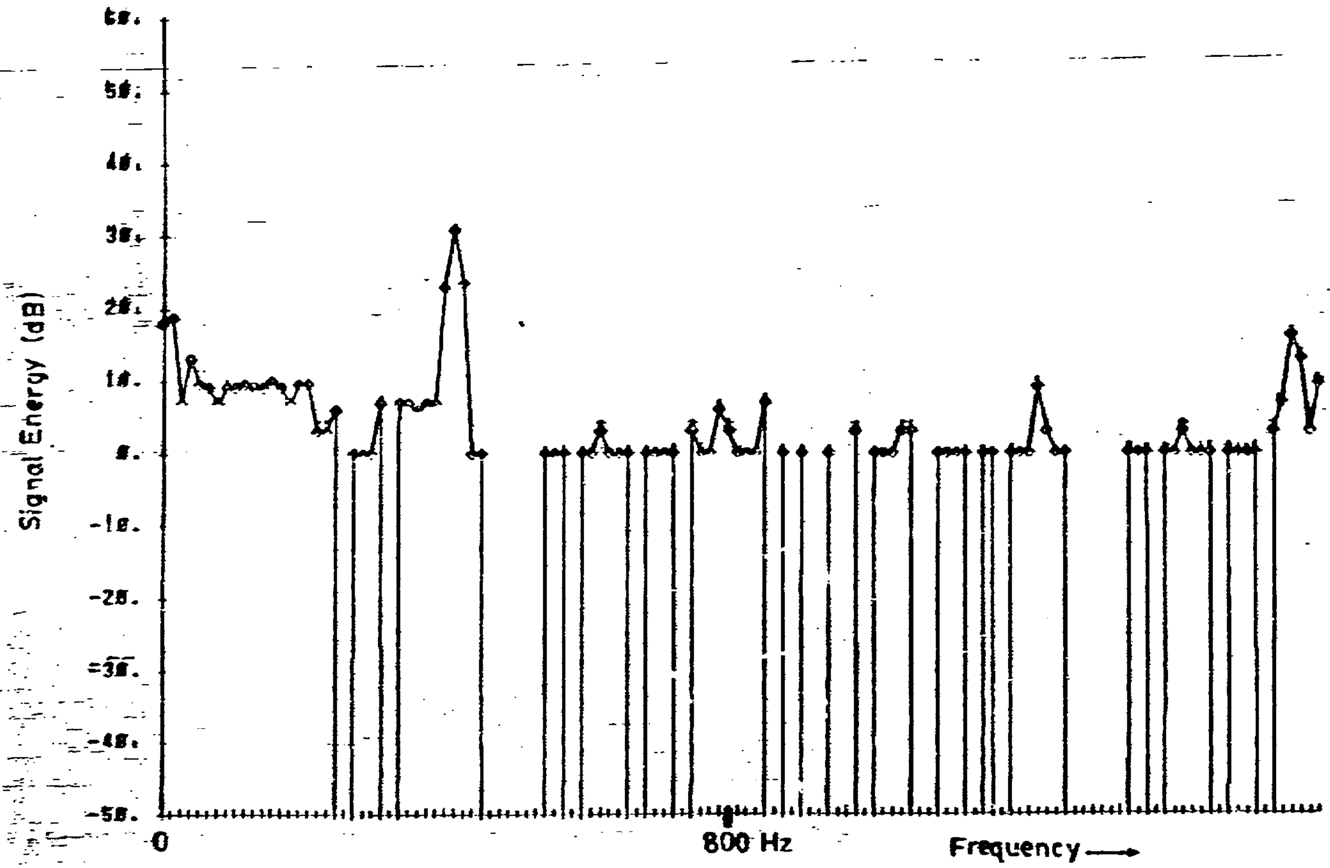
PRODUCED BY 'IWI.SJK-VTZE' ON 15MAR84 AT 14:19.41

RADAR HARDWARE SIMULATION -- SIGNAL PROCESSING OUTPUT

NO. OF BINS 8

NO. OF PULSES 128

P.R.I. 625.000 US



0.1 m^2 target at 1.59 Km

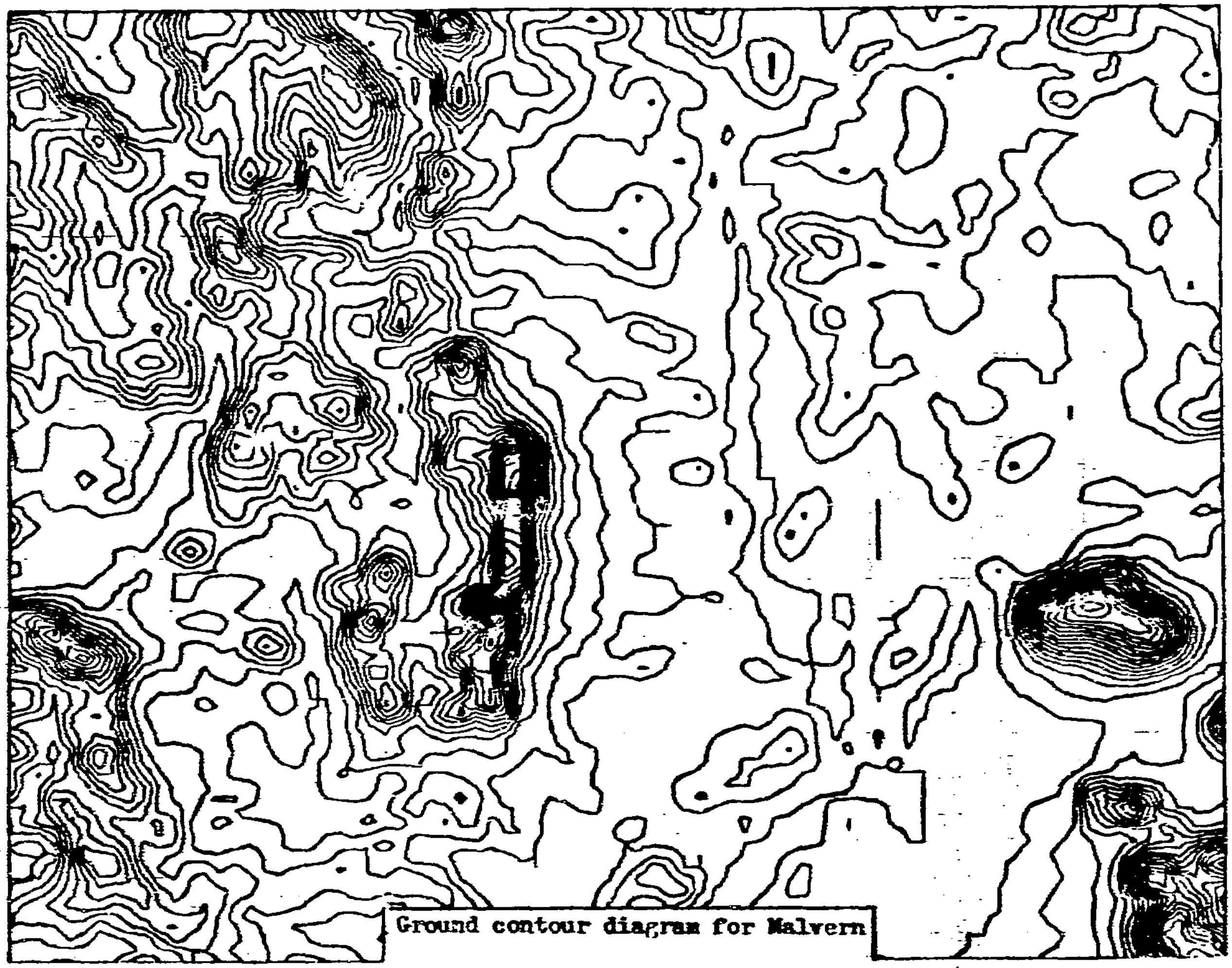
with MTI filter

FIGURE 15

PRODUCED BY ':RADSIM.SJK-VT2E' ON 11SEP84 AT 14.33.52 1

GROUND HEIGHT CONTOUR DIAGRAM

SITE NO 1.

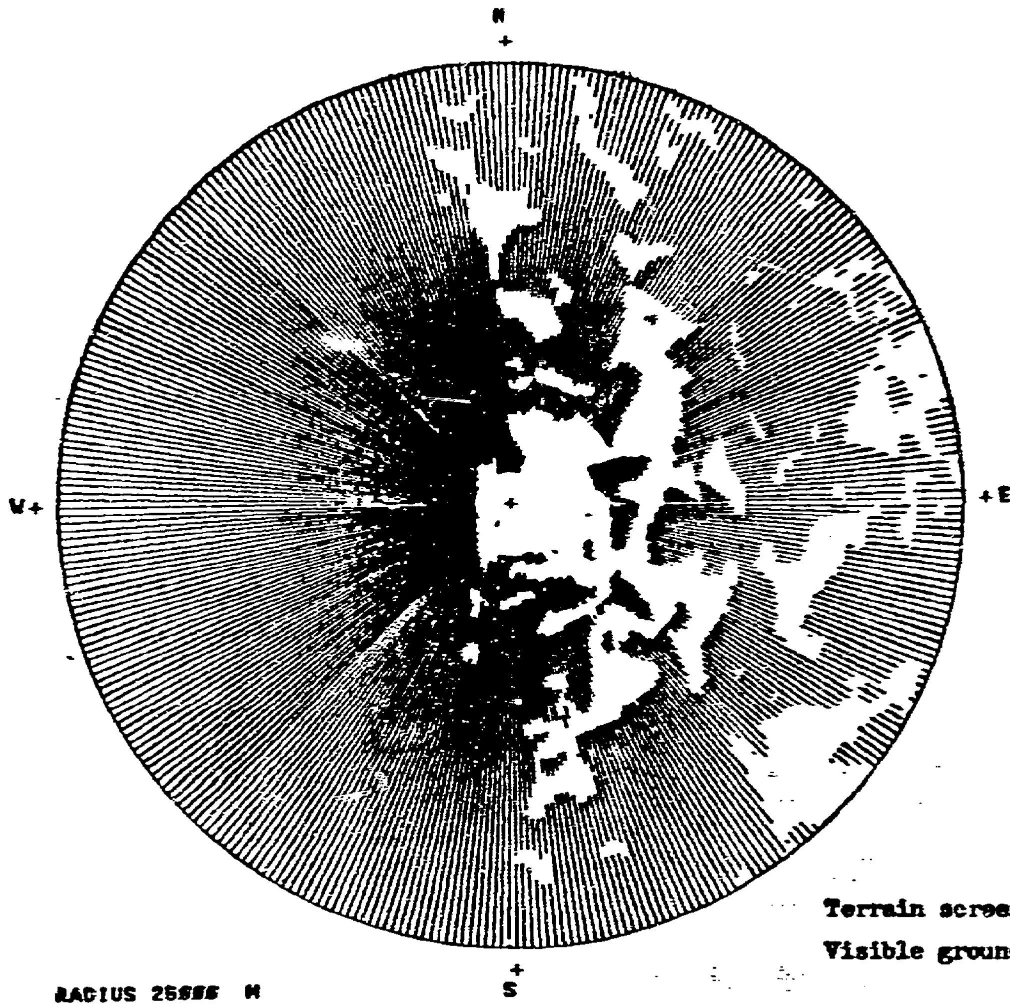


Ground contour diagram for Malvern

Cont··rs drawn at 15m intervals

FIGURE 16

PRODUCED BY ':RADSIM.SJK-CNET' ON 24AUG84 AT Ø9.41.28   1



RADIUS 25ØØØ M

TERRAIN ONLY

ØKM 1ØKM 2ØKM

Terrain screening diagram for Malvern

Visible ground is shown white

FIGURE 17

UNLIMITED

UNLIMITED

DOCUMENT CONTROL SHEET

Overall security classification of sheet ...UNCLASSIFIED...

(As far as possible this sheet should contain only unclassified information. If it is necessary to enter classified information, the box concerned must be marked to indicate the classification eg (R) (C) or (S))

1. DRIC Reference (if known)	2. Originator's Reference	3. Agency Reference	4. Report Security Classification
	Memorandum 3742		Unclassified

5. Originator's Code (if known)	6. Originator (Corporate Author) Name and Location
	Royal Signals and Radar Establishment
5a. Sponsoring Agency's Code (if known)	**6a. Sponsoring Agency (Contract Authority) Name and Location**

7. Title

MICROWAVE SENSOR DESIGN USING CAD TECHNIQUES

7a. Title in Foreign Language (in the case of translations)

7b. Presented at (for conference papers) Title, place and date of conference

8. Author 1 Surname, initials	9(a) Author 2	9(b) Authors 3,4...	10. Date	pp. ref.
Greenhalgh D	Kidd S J			

11. Contract Number	12. Period	13. Project	14. Other Reference

15. Distribution statement

Descriptors (or keywords)

continue on separate piece of paper

Abstract

A computer aided design facility is described that enables microwave sensors to be designed and optimised. The facility consists of a suite of computer programme modules, each of which emulates a typical radar subsystem and which may be linked with other modules to emulate a complete system. The sensor environment part of the facility includes both target and clutter models. The sensor hardware part of the facility includes nonlinear effects, and the ability to interchange recorded and simulated signals.

S80/48